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ARTICLE

Use of Vaccination against Enteric Septicemia of Catfish and Columnaris Disease by the U.S. Catfish Industry

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Abstract

Vaccination is an effective strategy used for the protection of food animals against infectious diseases. A 2010 U.S. Department of Agriculture questionnaire examined U.S. catfish industry use (in 2009) of two commercial vaccines that provide protection against enteric septicemia of catfish (ESC) and columnaris disease, catfish producers' opinions regarding the percentage of vaccinated fish they expect to be protected, and producers' general expectations regarding survival of vaccinated fish compared with unvaccinated fish. During 2009, 9.7% of the total fingerling operations used one or both vaccines; 12.3% of the total industry fry production was vaccinated against ESC, and 17.0% was vaccinated against columnaris disease. Of the producers who grew food-sized catfish to harvest, 6.7% used vaccinated catfish. The farms that did not use vaccinated fish for grow out had a mean size of 63.4 water surface hectares (156.6 water surface acres). The operations that used vaccinated fish were larger (mean size = 206.6 water surface hectares, or 510.6 water surface acres). The producers that stocked ESC-vaccinated fish for grow out represented 19.0% of the total water surface area of food fish production; producers that stocked columnaris-vaccinated fish represented 16.6% of the total area. Of the producers that stocked ESC-vaccinated catfish, 41.9% thought that survival was better in vaccinated fish than in unvaccinated fish; of the producers that stocked columnaris-vaccinated catfish, 46.2% thought that vaccinated fish displayed better survival. However, 37.5% of producers that used the ESC vaccine and 39.7% of producers that used the columnaris vaccine did not know whether vaccination improved survival rates. When all producers were asked about their expectations regarding the percentage of vaccinated fish that would be protected from disease, 52.4% responded that they expected 100% of their fish to be protected. More producer information about reasonable expectations regarding vaccine efficacy, the conditions under which immunosuppression and vaccine failure can occur, and assessment of vaccine performance may result in increased use of vaccination as a tool for the catfish industry.

Vaccines are an effective strategy used to protect food animals, including fish, against infectious diseases that negatively impact the health and productivity of animal production systems. Vaccination is now the single most important measure for prevention of bacterial diseases in farmed fish, especially salmonids (Håstein et al. 2005). Enteric septicemia of catfish (ESC) and columnaris disease are the most economically important bacterial diseases affecting the health and productivity of channel catfish *Ictalurus punctatus* across the U.S. catfish industry (Wagner et al. 2002). The vaccine AQUAVAC-ESC (Intervet, Inc., Millsboro, Delaware) is used to aid in prevention of ESC disease, which is associated with the bacterium

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Edwardsiella ictaluri. The vaccine AQUAVAC-COL (Intervet) is used as an aid in the prevention of columnaris disease, which is associated with the bacterium *Flavobacterium columnare*. The two vaccines contain a frozen preparation of avirulent live-strain bacteria (*E. ictaluri* for AQUAVAC-ESC; *F. columnare* for AQUAVAC-COL). Fish are vaccinated by immersion at an age of 7 d posthatch (dph) or greater. Vaccination is more economical when fry are vaccinated at a younger age (i.e., smaller size). The average cost to vaccinate fry at 7–10 dph is about US$0.004 per fish (Intervet/Schering Plough, personal communication).

The AQUAVAC-ESC vaccine has been available for use by the U.S. catfish industry since January 1999. Studies have demonstrated that it is safe and reduces mortality under laboratory and field conditions. Shoemaker et al. (1999) demonstrated in laboratory studies that percent mortality was significantly lower for channel catfish fry vaccinated at 12, 14, 16, or 31 dph than for unvaccinated fry; relative percent survival (RPS) values ranged from 45.3% to 79.5%. For fry that were vaccinated at 7 or 10 dph, results for tests of significance were not presented, but RPS values ranged from 58.4% to 78.9%. Wise and Terhune (2001) also demonstrated significantly reduced mortality in fry that were vaccinated at 12 dph. In laboratory studies, Wise et al. (2000) observed that the vaccine strain of *E. ictaluri* (RE-33) provided significant protection. There were also significant differences in vaccine efficacy between catfish families, although mortality was always lower in the vaccinated fish. Wise et al. (2000) reported that for fingerlings exposed to *E. ictaluri* in a natural pond, the vaccine provided significant protection if the fish were exposed to higher concentrations (i.e., 1×10^7 colony-forming units/mL) of the vaccine strain. In an experimental pond study that used vaccinated fry combined with a delay before releasing fry into fingerling ponds, Carrias et al. (2008) found that vaccination improved survival of fingerlings. Klesius and Shoemaker (1999) and Shoemaker et al. (2009) provide reviews of the development, safety, and efficacy of the *E. ictaluri* vaccine strain (RE-33) used in AQUAVAC-ESC.

The AQUAVAC-COL vaccine has been available since March 2005 and has been shown in laboratory studies to be safe and to improve survival when used to vaccinate eggs (Shoemaker et al. 2007) or young catfish. Shoemaker et al. (2011) found that administering AQUAVAC-COL to channel catfish fry at 10–48 dph resulted in an RPS of 57–94% and statistically significant differences in cumulative percent mortality. There are no published field studies of the AQUAVAC-COL vaccine's use with catfish, but Bebak et al. (2009) reported the results of a field trial in which vaccination with AQUAVAC-COL significantly reduced the risk of death from columnaris disease in feed-trained largemouth bass *Micropterus salmoides*.

The two vaccines are the only commercial vaccines available for use by the U.S. catfish industry. In the USA and worldwide, other vaccines are being developed to protect channel catfish from pathogens such as *Ichthyophthirius multifiliis* (Swennes et al. 2007), channel catfish virus (Harbottle et al. 2005), and *Stenotrophomonas maltophilia* (Geng et al. 2010; Wang et al. 2009). Work is also in progress to develop additional vaccines for ESC (Lawrence and Banes 2005; Karsi et al. 2009; Pridgeon et al. 2010) and columnaris (Olivares-Fuster et al. 2010; Pridgeon and Klesius 2010).

There have been almost no published studies or reviews that describe vaccine use by aquaculture industries, despite the fact that use of vaccination is widespread in aquaculture worldwide, especially for bacterial diseases and for high-value fish such as salmon (Håstein et al. 2005; Sommerset et al. 2005; Bravo and Midtlyng 2007).

Use of AQUAVAC-ESC was evaluated with a 2003 questionnaire administered by the U.S. Department of Agriculture (USDA) National Animal Health Monitoring System (NAHMS; USDA 2003a, 2003b). However, there is no information in the literature about current use of the ESC vaccine and there is no previously published information about industry use of the columnaris vaccine. Recently, the USDA NAHMS, which is tasked with continuous surveillance of animal health in the USA (Wineland and Dargatz 1998), developed a 2010 questionnaire to study management practices and health issues on commercial channel catfish farms that produce food-sized fish. Here, we examine the survey results relating to (1) use of AQUAVAC-ESC and AQUAVAC-COL by the catfish industry, (2) catfish producers' opinions regarding the percentage of vaccinated fish that they would expect to be protected, (3) producers' plans for future use of vaccines, and (4) producers' general expectations regarding the performance of vaccines against ESC and columnaris disease.

METHODS

Questionnaire.—The USDA NAHMS questionnaire was implemented during January 2010, when USDA National Agricultural Statistics Service (NASS) enumerators attempted to contact, either by phone or in person, all of the 691 catfish producers on their list of producers in Alabama, Arkansas, Louisiana, and Mississippi. These four states accounted for 91.5% of the commercial catfish sales in 2009 and 91.3% of the water surface area intended for catfish production use between January 1 and June 30, 2010 (USDA 2010a, 2010b).

As part of the NAHMS questionnaire, producers were asked about their 2009 use of the ESC and columnaris vaccines and the performance of vaccinated fish. They were also asked about disease outbreaks, regardless of whether there had been a diagnosis by a fish health professional. Specifically, catfish fry and fingerling producers were asked about vaccination of fry. Questions included the percentage of fry vaccinated, age at vaccination, whether there were disease outbreaks in vaccinated fish, and the producers' assessment of survival in vaccinated compared with unvaccinated fish. Producers of food-sized fish were asked whether they stocked vaccinated fish, the percentage of stocked fish that were vaccinated, whether there were outbreaks in ponds with vaccinated fish, their assessment about survival rates in vaccinated compared with unvaccinated fish, and whether they planned to stock vaccinated fish in 2010. All producers, whether they used the vaccine or not,

were also asked about the percentage of vaccinated fish they would expect to be protected if they were to stock fingerlings vaccinated against ESC or columnaris disease. Questions about vaccine use were not asked separately for channel catfish versus blue catfish *Ictalurus furcatus* or channel catfish × blue catfish hybrids. However, whenever possible during analysis, we looked for opportunities to distinguish use of vaccination for channel catfish compared with blue catfish and hybrids.

Data analysis.—The data collected during the NAHMS study were validated to identify and correct errors. Data were aggregated for the entire industry to avoid disclosure issues. Initial weights for all operations were all set to 1.0 because all operations on the NASS list were selected for the study. Weights were adjusted within state and farm size strata to adjust for nonresponse via the methods described by Dargatz and Hill (1996). Statistical estimation was completed by using SUDAAN software (Research Triangle Institute International, Research Triangle Park, North Carolina), which implements a Taylor series expansion to estimate appropriate variances for weighted data.

RESULTS

Percent Response and Overall Use of Vaccination

In total, 583 of the 691 producers on the NASS list responded to the NAHMS 2010 questionnaire, resulting in an 84.4% response rate. Questionnaires were completed by 424 producers that raised catfish in 2009.

The questionnaire asked about vaccine use during 2009. For the four states, 6.7% (SE = 0.4) of producers grew catfish that were vaccinated against ESC, columnaris disease, or both by (1) producing fry, (2) producing fingerlings that were vaccinated as fry, (3) stocking vaccinated fish for grow out, or (4) a combination of these. As subsequent data analyses broke down vaccine use into smaller and smaller units, the potential for the identification of individual producers increased. Therefore, to ensure confidentiality, data for the four participating states were combined for the analysis, and results are reported by using percentages.

Vaccine Use at the Fry Stage

Vaccination of fry against enteric septicemia of catfish.—About 1 in 8 producers (12.8%, SE = 0.5) raised fry to the fingerling stage. Only 3.9% (SE = 0.4) of these fingerling producers vaccinated the fry against ESC, and all vaccinated fry were channel catfish. Of the approximately 1.1×10^9 channel catfish fry that were hatched by the industry in 2009 (estimated from USDA 2010a and J. Steeby, Mississippi State University, personal communication), 12.3% were vaccinated against ESC. Fry were vaccinated at a mean age of 15.1 dph (SE = 0.6).

Vaccination of fry against columnaris disease.—Of the operations that raised fry to the fingerling stage, 9.7% (SE = 0.6) vaccinated fry against columnaris disease. Of the 1.2×10^9 fry (channel catfish, blue catfish, and hybrids) that were hatched by the industry (estimated from USDA 2010a and J. Steeby, personal communication), 17.0% (SE = 8.6) were vaccinated against columnaris disease. Fry were vaccinated at a mean age of 20.6 dph (SE = 0.8). All producers that vaccinated some fry against ESC also vaccinated some fry against columnaris disease. We could not determine the percentage of hybrids or blue catfish fry that were vaccinated against columnaris disease.

Use of Vaccinated Catfish during Grow Out

The results of the survey indicated that 94.1% (SE = 0.3) of producers stocked fish for grow out; of these producers, 6.7% (SE = 0.3) used at least some catfish that were vaccinated against ESC, columnaris disease, or both. Of the 36,219 water surface hectares (89,500 water surface acres; USDA 2010a) that were used by operations for the grow out of catfish, 7.4% were used for the grow out of hybrids. We could not determine the percentage of blue catfish or hybrids that were vaccinated against ESC or columnaris disease.

Farms that used at least some vaccinated fish for grow out had a larger average size than farms that did not use any vaccinated fish for grow out. Operations that grew out vaccinated fish used a mean ± SE of 206.6 ± 32.1 water surface hectares (510.6 ± 79.3 water surface acres) for production; operations that did not use vaccinated fish for grow out used an average of 63.4 ± 1.6 water surface hectares (156.6 ± 4.0 water surface acres). Among the operations that stocked fish for grow out, 6.2% (SE = 0.3) stocked fish that were vaccinated against ESC and 3.9% (SE = 0.2) stocked fish that were vaccinated against columnaris disease (Table 1). The higher percentage of operations stocking ESC-vaccinated fish—even though more fish were vaccinated against columnaris disease—reflects the fact that fish stocked in 2009 could have been vaccinated in 2008 or 2009.

Use of enteric septicemia of catfish-vaccinated fish during grow out.—We found that 6.2% (SE = 0.3) of producers stocked ESC-vaccinated fish for grow out; these catfish producers were

TABLE 1. Percentage (SE in parentheses) of catfish operations that stocked fish that were vaccinated against enteric septicemia of catfish (ESC) or columnaris disease (COL) during 2009; percentages were calculated based on the total number of operations that produced food-sized catfish (channel catfish, blue catfish, or their hybrids) and are presented according to farm size category (water surface hectares; acres in parentheses).

	Size (water surface hectares; acres in parentheses) of catfish operations				
Disease vaccine	0.4–8.0 (1–19)	8.1–20.0 (20–49)	20.1–60.6 (50–149)	≥60.7 (≥150)	Percentage for all operations
ESC	5.5 (0.7)	0	5.8 (0.6)	11.4 (0.7)	6.2 (0.3)
COL	5.6 (0.6)	0	3.3 (0.4)	6.3 (0.5)	3.9 (0.2)

TABLE 2. Percentage (SE in parentheses) of U.S. catfish producers that stocked vaccinated fish for grow out in 2009, percentage of total water surface area (all catfish farms: 36,219 water surface hectares) contributed by farms that stocked vaccinated fish for grow out in 2009, and percentage of stocked fish that were vaccinated at farms that used vaccinated fish for grow out in 2009. Fish were vaccinated against enteric septicemia of catfish (ESC), columnaris disease (COL), or both.

Variable	ESC	COL	ESC + COL
Percentage of farms that stocked vaccinated fish for grow out	6.2 (0.3)	3.9 (0.2)	3.4 (0.2)
Percentage of total surface hectares from farms with vaccinated fish	19.0 (2.6)	16.6 (2.7)	16.6 (2.7)
Percentage of fish that were vaccinated	79.2 (1.5)	67.9 (2.2)	67.6 (2.4)

located in Mississippi, Alabama, or Arkansas (Table 2). These farms represented 19.0% (SE = 2.6) of the 36,219 water surface hectares in production for grow out during 2009. Slightly more than 75% (79.2%, SE = 1.5) of the total number of fish stocked by these producers were vaccinated against ESC.

Use of columnaris-vaccinated fish during grow out.—We found that 3.9% (SE = 0.2) of catfish operations stocked columnaris-vaccinated fish for grow out (Table 2). These operations were located in Mississippi or Alabama and represented 16.6% (SE = 2.7) of the 36,219 water surface hectares in production for grow out during 2009. For these farms, 67.9% (SE = 2.2) of the stocked fish were vaccinated against columnaris disease.

Use of fish that received both vaccines for grow out.—Of the producers that stocked catfish for grow out in 2009, 3.4% (SE = 0.2) used fish that were vaccinated against both ESC and columnaris disease (Table 2). These farms represented 16.6% (SE = 2.7) of the 36,219 water surface hectares used for grow out. For these farms, a mean of 67.6% (SE = 2.4) of stocked fish were vaccinated against both diseases. However, 54.4% (SE = 3.5) of the producers that used vaccinated fish indicated that they vaccinated 100% of their stocked fish against both diseases.

Vaccine Performance for Grow-Out Operations

Performance of the enteric septicemia of catfish vaccine.—For operations that stocked ESC-vaccinated fish, 41.9% (SE = 2.5) reported that survival rates were better in vaccinated fish than in unvaccinated fish, however 49.9% (SE = 3.9) of those operators reported that some ESC outbreaks were observed in ponds with vaccinated fish (Figure 1a). Survival rates were reported to be the same in unvaccinated and ESC-vaccinated fish by 20.6% (SE = 2.1) of the producers that stocked vaccinated fish; 37.5% (SE = 2.5) of producers did not know whether survival rates were higher in vaccinated versus unvaccinated fish. Among the producers that did not know whether survival rates were higher with vaccination, 42.8% (SE = 4.1) did not observe any ESC outbreaks in ponds containing vaccinated fish.

Performance of the columnaris vaccine.—For operations that stocked columnaris-vaccinated fish, 46.2% (SE = 3.1) reported that survival rates were better in vaccinated fish than in unvaccinated fish; however, 71.1% (SE = 3.9) of these producers also reported that they observed some columnaris disease outbreaks in ponds with vaccinated fish (Figure 1b). Survival rates were reported to be the same in vaccinated and unvaccinated fish by 14.1% (SE = 2.3) of the producers that grew columnaris-vaccinated fish; 39.7% (SE = 3.0) of producers did not know whether survival rates were higher from columnaris vaccination. Among the producers that did not know whether survival rates were higher, 49.9% (SE = 4.6) did not observe any columnaris disease outbreaks in ponds containing vaccinated fish.

Expectations about the Effectiveness of Vaccination

Survey participants were asked what percentage of the vaccinated fish they would expect to be protected from disease if they stocked fingerlings that were vaccinated against ESC or

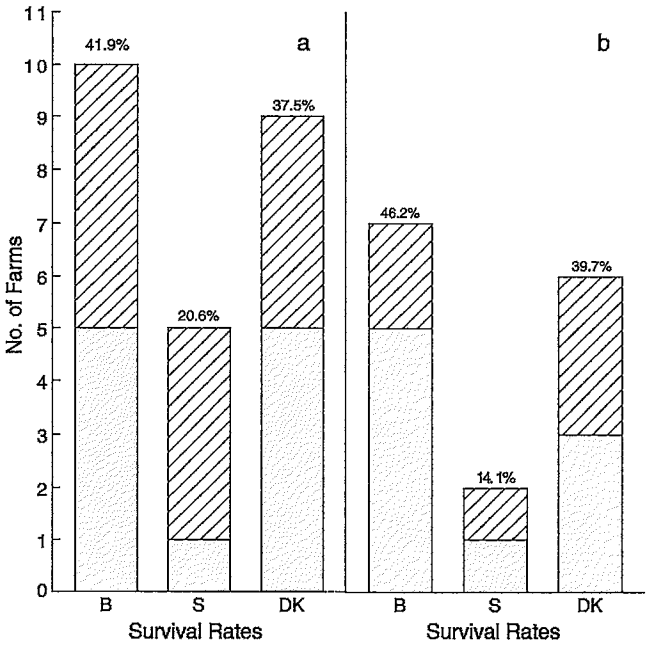

FIGURE 1. Questionnaire responses of catfish producers that grew channel catfish, blue catfish, or hybrids that were vaccinated against (**a**) enteric septicemia of catfish or (**b**) columnaris disease; three possible responses are depicted (B = producers who thought that survival rates of vaccinated fish were better than those of unvaccinated fish; S = producers who thought that survival rates were the same for vaccinated and unvaccinated fish; DK = producers who didn't know whether there was a survival difference between vaccinated and unvaccinated fish). The percentage of producers with each response is given above each bar; producers who did (gray shading) or did not (hatched areas) observe outbreaks in ponds with vaccinated fish are indicated.

columnaris disease. On average, operations that stocked vaccinated fish in 2009 expected 87.5% (SE = 1.3) of the fish to be protected. Those that did not stock vaccinated fish in 2009 expected, on average, 92.7% (SE = 0.1) of the fish to be protected. Among all catfish producers, 52.4% (SE = 0.6) expected 100% of the fish to be protected, 26.5% (SE = 0.6) expected 90–99% of the fish to be protected, 18.2% (SE = 0.5) expected 50–89% of the fish to be protected, and 2.9% (SE = 0.2) expected less than 50% of the fish to be protected (Figure 2).

Projected Use of Vaccinated Fish in 2010

Only 7.0% (SE = 0.3) of catfish producers planned to stock ESC-vaccinated fish in 2010. Of those planning to stock ESC-vaccinated fish, 66.7% (SE = 2.5) planned to vaccinate 100% of their fish. Of that same group, 37.9% (SE = 2.5) did not stock ESC-vaccinated fish in 2009 but planned to do so in 2010. The operations that planned to stock ESC-vaccinated fish in 2010 represented 18.0% (SE = 2.6) of the 36,219 water surface hectares used for catfish grow out during 2009.

Just 5.0% (SE = 0.3) of producers planned to stock columnaris-vaccinated fish in 2010. Of those planning to stock columnaris-vaccinated fish, 63.5% (SE = 3.0) planned to vaccinate 100% of their fish. Of that same group, 41.7% (SE = 2.9) did not stock columnaris-vaccinated fish in 2009. The operations that planned to stock columnaris-vaccinated fish in 2010 represented 16.3% (SE = 2.7) of the 36,219 water surface hectares used for catfish grow out during 2009.

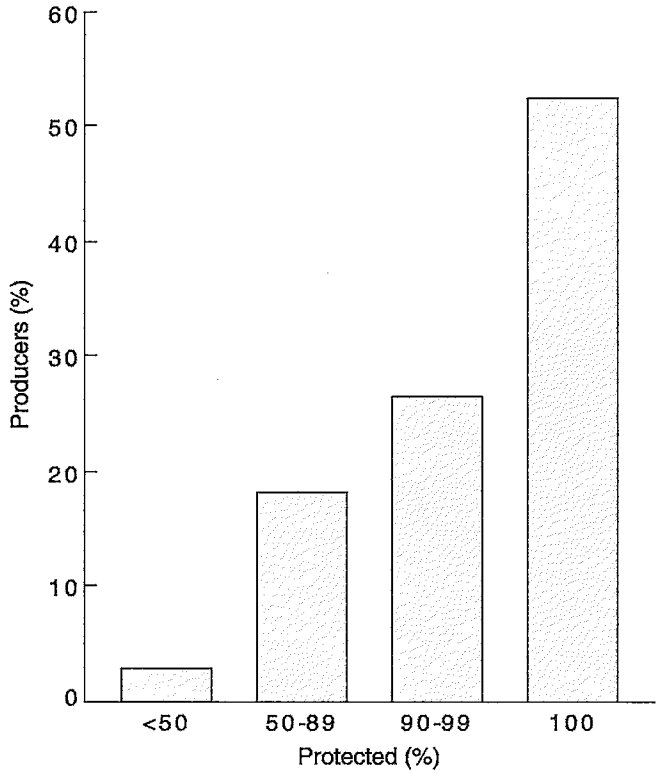

FIGURE 2. Catfish producers' expectations for the percentage of catfish that would be protected (<50, 50–89, 90–99, or 100% of fish protected) by vaccination against enteric septicemia of catfish or columnaris disease. The question posed was not specific to either vaccine.

DISCUSSION

The percentage of farmers that produced vaccinated catfish (i.e., vaccinated against ESC, columnaris disease, or both) indicates that a small fraction of the operations (6.7%) are taking advantage of vaccines to protect the fish used for grow out. These operations represented 16.3% of the total water surface area of production, but not all of the fish that were stocked into this area were vaccinated. Even among operations with 60.7 water surface hectares (150 water surface acres) or more, there has been a shift in the percentage that stock ESC-vaccinated fish. During 2001–2002 (the period covered by the 2003 NAHMS questionnaire), 16.5% of operations stocked ESC-vaccinated fish compared with 6.2% of the operations in 2009 (USDA 2003b).

The proportion of fry that are vaccinated against ESC by the U.S. catfish industry has been anecdotally reported to be as high as 25% of the fry produced (Shoemaker et al. 2009). In comparison with the results of the Shoemaker et al. (2009) study and previous questionnaires, the 2010 questionnaire results indicate that fingerling producers' use of the ESC vaccine to vaccinate fry has declined. The percentage of fingerling operations that vaccinated fry against ESC was 3.9% in 2009, whereas it was 11.4% in 2001 and 2002 (USDA 2003a). In 2009, ESC-vaccinated fry represented 12.3% of the total number of channel catfish fry hatched by the industry, far less than the percentages in 2001 (22.7%) and 2002 (18.1%).

Overall, based on producer responses regarding future plans for vaccine use, it appeared that there would not be much change between 2009 and 2010. Some producers indicated that they did not plan to continue vaccine use, but new farmers indicated that they intended to use vaccination, so the percentage of vaccinated fish was probably about the same in 2010 as in 2009.

There are many possible reasons for the decline in use of the ESC vaccine and for the low use of the columnaris vaccine by the catfish industry. Industry awareness about the availability of the vaccines is unlikely to provide an explanation for this low use, especially when considering that the ESC vaccine has previously been used more broadly and the columnaris vaccine has been available since 2005. Cost of catfish production has increased rapidly since the last NAHMS study was published, resulting in large declines in the size of the catfish industry and the level of production by the industry (USDA 2010a, 2010b). The decline in the use of vaccination may be a consequence of (1) producers' attempts to keep production costs as low as possible, especially among smaller operations; and (2) the lack of on-farm evaluation of the vaccines' performance and effectiveness in preventing or reducing the impact of disease. Alternatively, producers may be evaluating performance and judging that the vaccine's effectiveness in preventing disease and increasing production does not outweigh the costs of vaccination.

As was discussed by Thorarinsson and Powell (2006), vaccination is used to improve economic predictability, which requires a systematic assessment of economic risk by the farmer. Disease risk level, vaccine efficacy, market price, harvest weight, and feed costs have a profound influence on the financial impact of vaccination. Many aquaculture industries and individual farmers have carried out this risk assessment, either qualitatively or quantitatively, and have determined that a vaccination program is a cost-effective means of reducing risk and results in economic benefit. These producers have determined—probably through a combination of use on the farm and perhaps risk analysis—that the negative economic impact of disease is greater when vaccination is not used.

Published, peer-reviewed cost–benefit analyses of vaccine use are a critical need for the catfish industry. Sommerset et al. (2005) and Shoemaker et al. (2009) mentioned, in total, three non-peer-reviewed reports: an industry report, a meeting abstract, and a vaccine manufacturer claim. Two of these sources reported increased production efficiency for AQUAVAC-ESC, and one reported no effect. All of these reports are extremely difficult to access and contain almost no supportive data.

To our knowledge, there has been no information published on use of vaccines for catfish production in other countries besides the USA. However, in comparison with other aquaculture industries, vaccine use by the U.S. catfish industry is relatively low, both in terms of the number of vaccines available and the extent of use by the industry. Håstein et al. (2005) sent a survey to 41 countries to identify fish species for which vaccines are used. In addition to channel catfish in the USA, vaccination is used for at least 12 species of marine and freshwater fish, including Atlantic salmon *Salmo salar*, rainbow trout *Oncorhynchus mykiss*, sea bass *Dicentrarchus labrax* (also known as European bass *Morone labrax*), gilthead seabream *Sparus aurata*, barramundi *Lates calcarifer* (also known as barramundi perch), tilapia *Tilapia* spp., turbot *Scophthalmus maximus*, yellowtail *Seriola quinqueradiata* (also known as buri), greater amberjack *Seriola dumerili*, and striped jack *Caranx vinctus* (also known as cocinero). Vaccines are available against Gram-negative bacteria (e.g., *Vibrio anguillarum*, *Aeromonas salmonicida*, and *Yersinia ruckeri*) and Gram-positive bacteria (e.g., *Streptococcus iniae*, *Lactococcus garvieae*, and *Renibacterium salmoninarum*). Vaccines against viruses (e.g., infectious pancreatic necrosis virus, pancreas disease virus, and infectious salmon anemia virus) are available, but there are no vaccines for parasitic diseases (Sommerset et al. 2005). Håstein et al. (2005) concluded that vaccine availability and use are more common in Europe than in the rest of the world.

The greater the apparent benefit in reducing the cost of production, the more likely are the producers to keep using the vaccine. Bravo and Midtlyng (2007) reviewed use of fish vaccines in the Chilean salmon industry for the 1999–2003 period. During that time, more than 20 vaccines were brought to market. Bravo and Midtlyng (2007) found that vaccination against certain diseases, such as enteric redmouth disease (caused by *Y. ruckeri*), is a common industry practice in salmonid production. Their data also indicated that, depending on the vaccine, use by the industry could fluctuate from year to year. For example, use of the salmonid rickettsial septicemia (causative agent: *Piscirickettsia salmonis*) vaccine in Chile declined from 51% in 2001 to 20% in 2003. Doubts about efficacy may be responsible for reduction in use of the salmonid rickettsial septicemia vaccine (Bravo and Midtlyng 2007). Some estimates for vaccine protection of salmon ranged from more than 75% against enteric redmouth disease to as low at 10% against bacterial kidney disease (caused by *R. salmoninarum*); over the 4-year period covered by their survey, Bravo and Midtlyng (2007) found that some of the vaccine use was not above 25% of the industry.

In our study, a surprisingly high percentage of producers—slightly more than one-third for each vaccine—did not know whether survival rates were higher in vaccinated fish than in unvaccinated fish. This lack of ability to assess vaccine performance could have been due to any of several factors, including misdiagnosis by the producer, limited effectiveness of vaccination, the length of time for which the vaccinated fish were cultured, the percentage of fish that were vaccinated, and the uncertainty in inventory tracking of pond-cultured catfish in the USA. The inability to accurately assess pond inventory could be an impediment to adopting vaccine use because producers may be unable to evaluate small but economically important changes in survival.

The relatively low use of vaccination may also be related to producer expectations for vaccination in preventing disease. Slightly more than 50% of the producers responded that they expected 100% of the vaccinated fish to be protected, even though millions of animals are being vaccinated and many factors affect development and maintenance of immunocompetence and the ability to resist clinical disease upon exposure to the etiological agent. To take advantage of the protection afforded by vaccination, producers must manage the fish in a way that optimizes the ability of the immune system to respond, and those optimal conditions must be maintained throughout the production cycle. For example, during vaccination, fish must not be stressed and they must receive the dose needed to mount an effective immune response. Nutritional status is also extremely important. After vaccination and throughout the production cycle, fish must receive the nutrition they need to develop and maintain an effective immune response. Colder water temperatures will also affect the immune response, and the reduced feeding that occurs during winter may affect immunocompetence in the spring (Roth 1991; Martins et al. 2011).

We have demonstrated that (1) use of the ESC and columnaris vaccines are low relative to the importance of the two diseases for the catfish industry and (2) use of the ESC vaccine by the catfish industry is lower than indicated by previous assessments. Producer education about reasonable expectations regarding vaccine efficacy, the conditions under which immunosuppression and vaccine failure can occur, and assessment of vaccine performance may result in increased use of vaccination as a tool for the industry.

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